Anisotropic Plasticity Constitutive Law for Sea Ice

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LONG-TERM GOAL

My long term goal is to develop sea ice dynamics models that describe behavior on kilometer scales and larger, and to base these models on the smaller scale physical processes known to control leading, rafting, and ridging.

OBJECTIVES

My three-year contract has five tasks: (1) complete development of the model and test it with *0d* calculations, (2) incorporate the model into a *2d* numerical code and test its performance by comparing behavior with observed behavior during the SIMI Main Experiment and at other times, (3) extend my ambient noise model by developing a process-based noise source for ridging and to relate the noise-generating model to ice mechanical behavior, (4) help transfer the new models into fleet systems such as PIPS, and (5) publish the results.

APPROACH

To meet our goals, we are developing a new anisotropic plasticity constitutive law to describe and forecast ice stress, deformation, lead direction, and ice condition at scales from a few kilometers to hundreds of kilometers. The essential difference between this anisotropic plasticity model and previous isotropic models is that it can describe the formation and direction of each new lead or ridge system and track its thickness distribution.

WORK COMPLETED

The anisotropic elastic plastic constitutive law has been formulated [*Coon, et al.*, 1992, 1998; *Pritchard*, 1998a]. I have formulated a new oriented thickness distribution to describe anisotropic ice conditions, and introduced a new method to integrate the constitutive equations [*Pritchard*, 1998b].

RESULTS

A complete set of mathematical equations has been developed to describe the anisotropic elastic plastic constitutive behavior [*Pritchard*, 1998a]. The yield surface is described in the three dimensional space of stress components rather than the two dimensional space of stress invariants. A normal flow rule is used, along with a stiff linear isotropic elastic response. The kinematic relationship between elastic and plastic stretching allows large deformations.

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Two different formulations have been introduced. *Coon, et al.* [1998] describe the formation and evolution of individual lead systems, with a thickness distribution for each. It is useful for Lagrangian descriptions. *Pritchard* [1998a] introduces an oriented thickness distribution in which all ice is oriented. In this latter model, isotropy is a state in which equal fractions of ice having all orientations appear. This oriented thickness distribution depends continuously on thickness and direction. It is useful for both Lagrangian and Eulerian descriptions.

I am now studying data to conduct *0d* simulations of model behavior. For these simulations, the stress and thickness distribution histories are determined by integrating the deformation history at a single location. My first goal is to determine the directions in which new leads form. We believe that a single lead may form when the stress reaches the tensile cutoff cone, where the traction across the newly formed lead must be zero. We do not yet understand whether pairs of leads may form along sliplines, where they are held together by a confining stress. I now believe that flaws may form along these sliplines, but a lead cannot form until the stress across the lead is zero, even if plastic opening occurs. This belief might be impossible to test because the stiff elastic behavior implies that stress goes to zero with only a very small amount of opening.

IMPACT/APPLICATION

Treating sea ice as an anisotropic material is a major scientific advance. First, leads are essential features, but previous models could not describe a lead or ridge system explicitly. Second, the leads, rafts, and ridges have very different behavior across and along their axes, but previous ice dynamics models could not describe this anisotropic behavior. Third, we can estimate the force needed to shear or close a lead by considering directly the buckling and rafting forces for different ice conditions. The anisotropic constitutive then incorporates these forces directly. Fourth, the ability to describe and forecast leads and their directions can have a big impact on ship routing. Fifth, the amount of open water estimated from satellite images can be seriously in error if we ignore lead directions. Finally, the noise generated by a ridge (for which the deformation may be correlated along its length) can differ from the noise generated by a set of uncorrelated neighboring points.

TRANSITIONS

I will work with other investigators to make the constitutive law available for use in other research codes and in Navy operational ice forecasting systems. I will work with Navy personnel and contractors to convert the research code into coding that is compatible with existing codes such as PIPS.

RELATED PROJECTS

The technical approach requires collaboration with M. Coon (NorthWest Research Associates, Inc.). A formal Management Plan was prepared to describe how we will collaborate, and how we will prevent duplication of our efforts so that we meet our goals with the scarce resources available.

I am working with R. Bourke, J. Wilson, and W. Hibler to install an ambient noise model into PIPS and/or other codes. I am helping to define the best proxy variables available in the PIPS model. This model defines strength of a viscous plastic model differently from the energetics argument used in my elastic plastic model [*Pritchard*, 1981]. In PIPS 2 we can estimate only the total rate of dissipation of plastic energy, but we need more work to isolate noise from the different processes. I will explore

ways to modify the PIPS strength calculation to allow for separate calculation of ridging and shear ridging, microcracking, mixed layer shearing, and other processes [*Pritchard*, 1984, 1990].

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